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CHAPTER 196

Computers in the Intensive Care Unit: A Match Meant to Be!

Reed M. Gardner, PhD · *Dean F. Sittig, PhD*
Terry P. Clemmer, MD

The care of critically ill patients places exceptional demands on physicians and nurses. As a result of their medical problems, patients in intensive care units (ICUs) are monitored with elaborate bedside monitors and are subjected to a wide variety of laboratory tests. Therapy is complex, timing of treatment is critical, and careful documentation of the care given is essential. A large volume of data must be stored, processed, and used for clinical decision making. The tremendous growth in the volume of medical information, the demand for cost-effective care, and the need to document and justify why clinical decisions are made have placed a large burden on the medical care team. Patients, payers, the public, and healthcare policy makers are increasingly demanding accountability, insisting that complete and accurate records be kept by physicians, nurses, and therapists who care for the critically ill.[1–6]

Since the late 1960s, rapid development in computer technology has occurred, with remarkable reductions in computer cost (from \$500,000 to less than \$5000) and size (from room-sized units to laptop models) as well as an almost 1000-fold improvement in computing speed and a reduction in power consumption.[7, 8] Approximately every 1.5 years, the performance-to-price ratio for computers doubles. The latest (Pentium) silicon microprocessor chip announced by Intel (Portland, OR) executes 100 million instructions per second and contains 3 million transistors, all within the area of a postage stamp. In just over 12 years since the original IBM personal computer was introduced, computing speed has increased 20-fold, the number of components for computers 150-fold, and the computing capability 500-fold. With the increasing capability and decreasing cost of computing, the possibility of using computers to help solve the problem of data collection, storage, and decision-making support needs of the ICU is very attractive. It seems apparent that, as the complexity of critical care increases and the cost of computer hardware decreases, every ICU will soon use not just one but several interconnected microcomputers.

ICUs have become an integral part of most hospitals. Their concentration on the treatment of the critically ill has made the acquisition and proper use of data extremely important. In the modern ICU, computerized monitoring devices and recording systems are common. This chapter outlines how computers can be used for record keeping and decision making.

COMPUTERIZED RECORD KEEPING

Barnett[9] recently reviewed the application of computers to ambulatory practice and quoted Florence Nightingale's 1873 book entitled *Notes on a Hospital:*

> *In attempt to arrive at the truth, I have applied everywhere for information, but in scarcely any instance have I been able to obtain hospital records fit for any purpose of comparison. If they could be obtained, they would enable us to decide many other questions besides the one alluded to. They would show the subscribers how their money was being spent, what good was really being done with it, or whether the money was not doing mischief rather than good.*

It is surprising that Florence Nightingale's comments are still applicable over 120 years later. The same holds true for today's ambulatory and ICU patients' records.

The medical record remains the principal instrument for ensuring the continuity of patient care. The Institute of Medicine of the National Academy of Sciences declared that a computer-based patient record was an essential technology for healthcare in the United States.[10, 11] Information in the record should be easily retrievable and reviewable in a temporal relationship with the associated data. There is a real need to integrate and organize patients' records to optimize medical data review and decision making.[12–15] As the central focus of the care process, the traditional handwritten medical record has several limitations:

1. It might be physically unavailable because it can only be used by one person at one location at any given time.
2. It is often poorly organized, with information available only in the order that it was recorded. Also, this information is often illegible. Thus, information retrieval may be impossible, slow, or susceptible to error.[6]
3. Retrieval of data from the record for research is time consuming and cumbersome because it must be done manually.[16]
4. The everincreasing number of bedside computerized instruments present data in electronic form, and this data must be read by a human and written onto the record.

In complicated cases, the conventional record is less helpful than a structured flow chart. Whiting-O'Keefe and associates have shown that structured records are easier to review, decrease review time, and improve information flow.[13] Criticisms of manual records are especially germane to the critical care medical records because of the large amount of data collected and the pressure to make prompt treatment decisions in the ICU. The importance of having a unified medical record has been demonstrated by a study conducted at LDS Hospital (Salt Lake City, UT).[17] In this study, detailed records were kept of the data used by physicians to make treatment decisions during teaching "rounds" in a shock-trauma ICU (Fig. 196–1). It was a surprise to find that laboratory data (42%) were the most frequently used data (clinical laboratory: 33%; blood gas values: 9%), since physiologic bedside monitors have become synonymous with the modern ICU. Drug and fluid balance data were next (22%), followed by clinicians' observations (21%); the bedside physiologic monitor accounted for only 13% of the data used in making therapeutic decisions during teaching rounds. These findings also provide evidence that data from several sources, not just from the traditional physiologic bedside monitoring devices, must be communicated and integrated into a unified medical record to permit effective decision making and treatment in the ICU.

INTEGRATED INTENSIVE CARE UNIT COMPUTER RECORDS

Computer charting in the ICU must support multiple types of data collection to be effective. As can be seen in Figure 196–1, a large portion of the data needed to make decisions is from "physical" tasks, such as administration of a medication or auscultation of breath or heart sounds. At present, most data of this type must be entered manually. Thus, for computer charting systems to be successful, computers must be able to collect a wide variety of data from bedside monitors as well as from nurses and physicians at the bedside. Unfortunately, in the past, most attempts at computerized charting have dealt only with a limited set of data, such as that acquired from electronic bedside monitors.

Figure 196–2 illustrates the complexity of ICU charting. The patient record (chart) must document the actions taken by the medical staff to fulfill both medical and legal requirements (#1 and #2). In addition, much of the data that are logged on the chart are used for management (#3) and billing (#4) purposes. Many computer systems have ignored these requirements and unwittingly force the clinical staff to double-chart. Efficient management in hospitals is a must, especially with the public's current awareness of healthcare issues in the United States.[18–22] Hospitals now have strong incentives to know the cost of procedures and to control these costs. As a result, knowing a patient's acuity (i.e., how sick he or she is) is a necessity, not a luxury; this knowledge makes it possible to project nursing staff needs and to account for the care of patients based on acuity rather than on a fixed room charge.

Communication of information (#5) to and from other departments within a hospital is mandatory. Convenient and timely access to clinical and administrative information from a physician's home or office via modem and a personal computer link is essential. A computerized record allows this type of communication. Since the computerized ICU record is stored in the system, it is also readily available for concurrent or retrospective research purposes (#6). Continuity of care is particularly important for critically ill patients, who are generally cared for by a team of physicians, nurses, and therapists who frequently communicate data to one another. For example, a laboratory technician calls a ward clerk, who reports data to a nurse, who in turn passes the information on to a physician, who then makes a decision based on the data. Each step in this "human" transmission process is subject to delay and error.

For computers to be most useful in the ICU, an integrated patient data management system must exist.[23] Even though excellent progress has been made in the field of computerization in the ICU, many challenges have yet to be faced. These challenges and opportunities are discussed in the sections that follow.

Development of Better Data Entry Techniques

Computerization of patient monitoring and of all available patient data requires further development of data entry methods. At present, a ballpoint pen and a blank piece of paper provide a fast, easy, familiar, and convenient method for physicians, nurses, and others to chart patient information. Unfortunately, the conventional handwritten chart has many deficiencies, as noted earlier. However, the ease and flexibility of charting with the usual manual method are still the standard against which ICU computer charting is compared. Therefore, data entry methods that are efficient and effective for data recording and review must be developed. It is highly likely that such methods will include some of the newer screen and graphic functions that have become

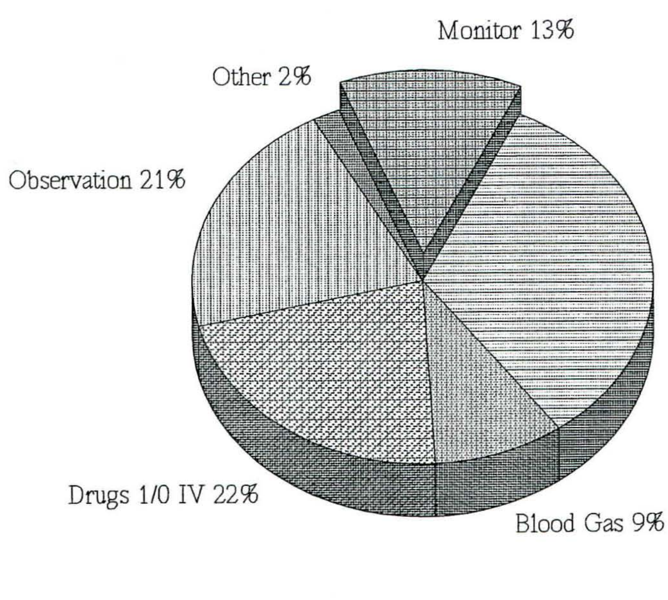

Figure 196–1. A pie chart showing data used for clinical decision-making by physicians during teaching rounds in a shock-trauma ICU. (From Bradshaw KE, Gardner RM, Clemmer TP, et al: Physician decision-making: Evaluation of data used in a computerized ICU. Int J Clin Monit Comput 1984; 1:81. Reprinted by permission of Kluwer Academic Publishers.)

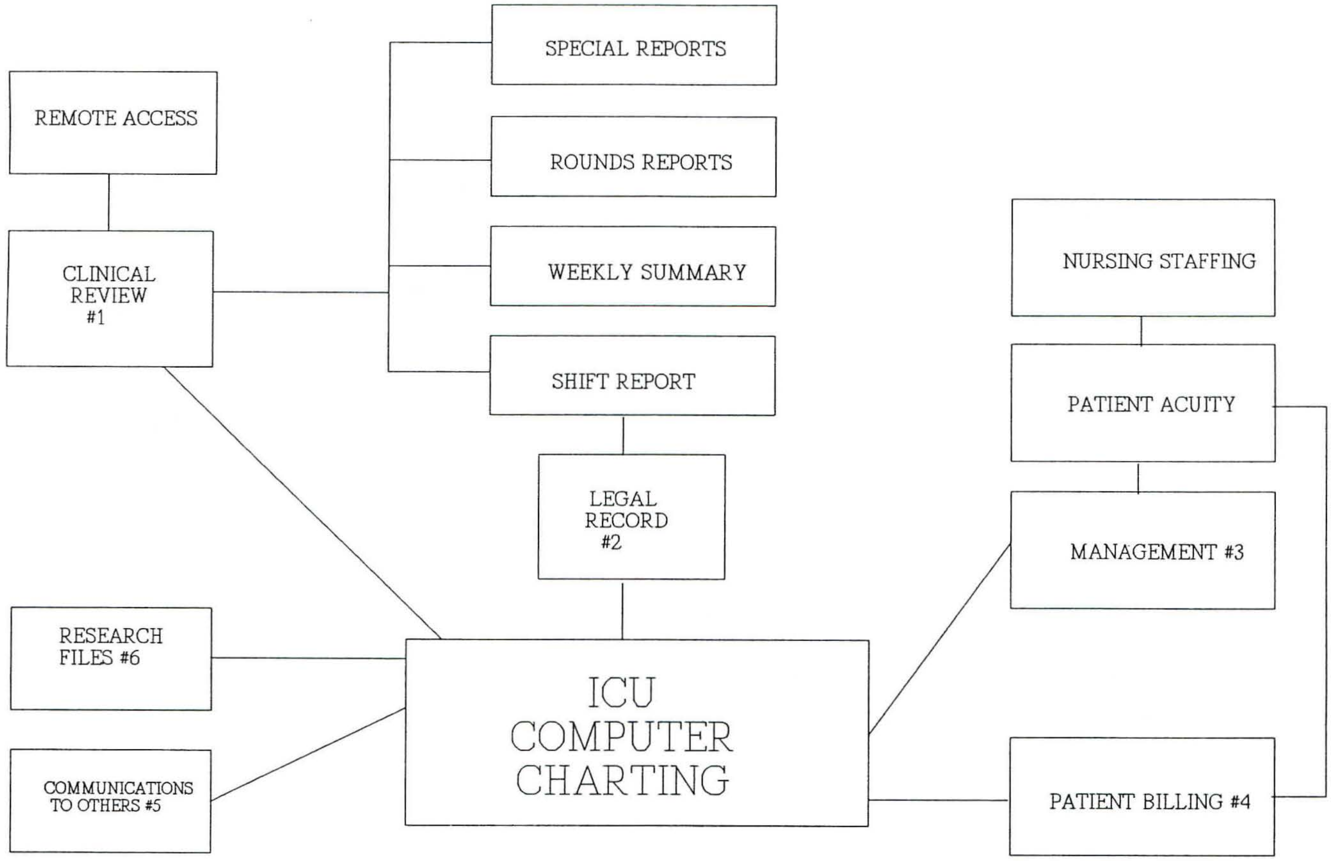

Figure 196–2. A block diagram showing the six major areas where computerized ICU charting interacts with nurses and physicians to make patient care more functional and efficient. See the text for an explanation of each function.

available with personal computers.[7] These devices include the mouse and floating cursor, light pens, and touch-sensitive monitor screens. Although each of these aids may help in entering data, the largest payoff is likely to be gained from a "smart" system. With a smart system, the terminal or work station at the bedside knows a great deal about a patient: his or her condition; what drugs have been prescribed with their dose, route of administration, and schedule; and the personal preferences of the physician caring for the patient. Thus, by being "smart," the computer system is able to present quickly personalized data entry and review menus, helping a nurse or physician to customize the care process. Also, innovative methods, such as "charting by exception," must be explored as healthcare providers become more aware of what the essential frequency of need and content of the chart should be.

Physicians, nurses, and therapists collect a large amount of data by making frequent observations, performing tests, and checking continuous monitoring equipment. Physicians generally prescribe complicated therapy for ICU patients. As a result, enormous amounts of clinical data accumulate. Physicians can miss important events and trends if accumulated data are not presented in a compact, well-organized format. In addition, the problems of managing these patients have been made even more challenging by economic pressures to reduce the cost of care.[18–22]

Figure 196–3 shows how nurses in a thoracic ICU (post–open heart surgery patients) spend their working day. As one would expect, nurses spend the majority of their time providing direct patient care (48%). Another 19% of their time (over 2 hours and 15 minutes per 12-hour shift) is spent documenting (charting).[24] The next most frequent activity (7%) is the communication of patient status information to other members of the healthcare team. Through the use of a good hospital computer system, the quality, accuracy, and ease of data communication within the ICU can be improved.[25, 26] An opportunity to reduce the data-handling time of the nursing staff also exists.

Standardization of Data Transfer Among Computers

Communication is one of the most important tasks of the healthcare professional. Data underlie the making of every medical decision. Except for personal observations made by and acted upon by physicians, nurses, and therapists at the bedside, all patient data must be communicated. Often, the data are communicated through several people and by several media before they get to the appropriate medical decision maker. Each step in the process, especially if it involves a handwritten record, can also result in delays and errors. Computers can solve these problems and are being used in more and more healthcare facilities to enhance communication. As can be noted in Figures 196–1 and 196–2, much of the data used to manage the treatment of patients comes from locations other than the bedside, such as the clinical laboratory. If ICU data are to be integrated with data from other computer systems, such as laboratory data, communications standards become crucial. Standards are now being developed that will make the task of "sharing" data among multiple computers in a hospital easier and more

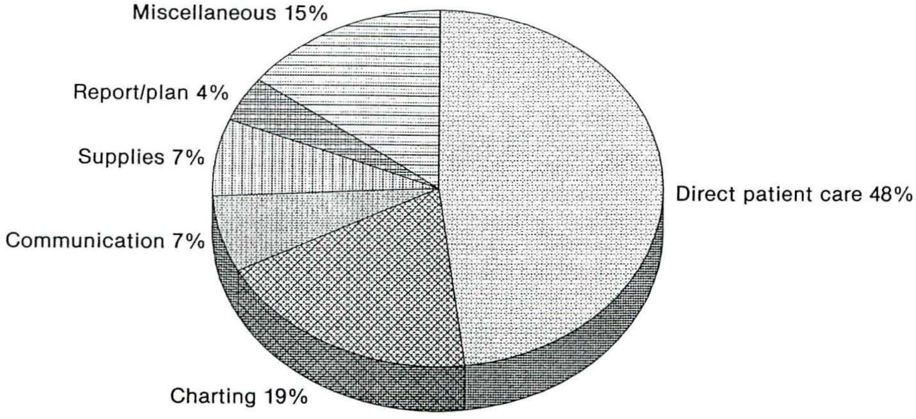

Figure 196–3. A pie chart indicating how nurses spend their time in a thoracic surgery ICU.

efficient.[27–34] Also, methods for better protecting patients' privacy in regard to computerized records are becoming highly advanced.[15, 33]

Medical Information Bus

By 1993, virtually every bedside patient monitor or support device (e.g., intravenous infusion pumps, ventilators, pulse oximeters, and physiological monitors) contained at least one and sometimes several microcomputers. However, since each device was usually made by a different manufacturer, it typically had its own display and was designed to work by itself, or "stand alone." As a result, common practice required that a nurse or therapist read data from the computer display of one of these devices (e.g., a pulse oximeter) and then manually enter the data into a computer terminal to get the data into the ICU's data base computer. An integrated "medical information bus (MIB)" that permits electronic acquisition of data from many different devices would be welcomed by all healthcare providers. Such a system would permit "real-time" data acquisition with little effort and almost no data entry errors. Currently, a committee of the Institute of Electrical and Electronic Engineers (IEEE) is working on the development of a standard for the MIB (IEEE Standard P1073).[27–30] The MIB communications system permits connection of each individual bedside device into a network, allowing almost instantaneous communication with each device. The communication technology being developed will allow the connection of a variety of bedside devices to a main computer and will automatically record their data.

The potential for more accurate and timely data acquisition as well as for labor reduction is enticing. However, the following problems still exist[27–30]:

1. The IEEE has not yet completed its standardization of the MIB standard. However, several of the initial standards have been written and approved.
2. Complex electrical device interfacing problems exist because there is no standard.
3. Complex "people" issues related to data acquisition exist; these include data ownership (e.g., should a nurse or a respiratory therapist enter a patient's fraction of inspired oxygen?), timely recording of data (what is "timely recording"? within 1 minute, 5 minutes, or 1 hour after the data is known?), and the selection and entry of representative data (should one select the high, low, or some other value for the recording interval selected?).

In our work and in that of Gravenstein and his colleagues, many of these issues are now being addressed.[30, 31] Based on several years of experimentation and experience, we have recently made recommendations about these issues.[31]

Better Data and Patient Quality Control Methods

In recent years, the work of Demming[34a] and others has been used to help improve the quality of many of the consumer products we purchase, such as automobiles and television sets. For medicine, Berwick tells us, "Real improvement in quality depends, according to the Theory of Continuous Quality Improvement, on understanding and revising the production process on the basis of data about processes themselves. Every process produces information on the basis of which the process can be improved."[35]

A computerized record remains the principal instrument for ensuring the continuity of care. Several authors have demonstrated that computerized methods can improve the quality of ICU patient care by alerting, reminding, and directing.[36–41] For example, Tate and associates have shown that computerized laboratory alerting leads to a significant increase in the proportion of patients in life-threatening situations who receive appropriate care and reduces the duration of the life-threatening alert condition as well as the length of stay in the hospital.[39] Elliott has shown that the computerized quality assurance monitors of respiratory therapy technologists improve staff member performance when measured against the department's stated policies and procedures.[40] Using computerized methods, Classen and associates found that adverse drug events in a general hospital were actually 80 times more prevalent than was originally thought based on the manual reporting of such events.[41]

DECISION MAKING AND ACCESS TO A MEDICAL KNOWLEDGE BASE

Guidelines for patient care have become widely discussed and applied.[42–46] In 1991, the Society of Critical Care Medicine embraced the concept of using guidelines for care.[46] Guidelines serve to ensure universal delivery of specific and well-accepted standards of care. Guidelines also ensure a minimum level of competence on the part of care providers and that the equipment and surroundings provided within an ICU are adequate. Although the use of computers has not yet been incorporated into formal guidelines, on the basis of the continuous quality improvement topics discussed earlier in this chapter, it is clear that computers can be used as devices to assist in the following of guidelines and improvement of patient care in the ICU.

The mark of a good physician is the ability to make sound clinical judgments. Medical decision making has traditionally been considered an artful and intuitive process rather than a scientific process. In recent years, however, computerized medical decision making has gained greater acceptance.[47–55] Indeed, the discussion of artificial intelligence is commonplace in medicine today. Use of the computer to assist in the complex task of medical decision making in the ICU has just begun.[47]

Computer-assisted decision support has been used in the ICUs at LDS Hospital in Salt Lake City for several years.[48–55] Figure 196–4 is a block diagram of the Health Evaluation through Logical Processing (HELP) computer system used at LDS Hospital. For an ICU patient, the HELP system collects and integrates data from a wide variety of sources. The data are automatically processed by the HELP decision-making system to determine whether the new information by itself or in combination with other data in the patient record, such as laboratory results or a previously generated decision, leads to a new medical decision. These computer-generated medical decisions are based on criteria (knowledge base) stored on the hard drive.

The HELP decision-making system has been used in the following areas: (1) interpretation (e.g., blood gas and hemodynamic parameter interpretation); (2) diagnosis; (3) alerting (i.e., the notification of life-threatening events); and (4) suggestion of treatment.

Development of Methods to "Standardize" Care

The development of algorithms for the care of the critically ill is a new and developing field. Use of the computer to provide clinical treatment instructions to physicians and other caregivers is appealing. Making treatment recommendations using computer methods is currently the most feasible. The art of medicine must be combined with the sciences of medicine to develop the best set of treatment strategies so that the best medical care can be made available to all. Chapter 101 presents further detail of the use of computerized algorithms for patient care.

DEVELOPMENT OF INTENSIVE CARE UNIT PATIENT DATA MANAGEMENT SYSTEMS

Until 1993, the development of computerized patient data management systems has taken place primarily in universi-

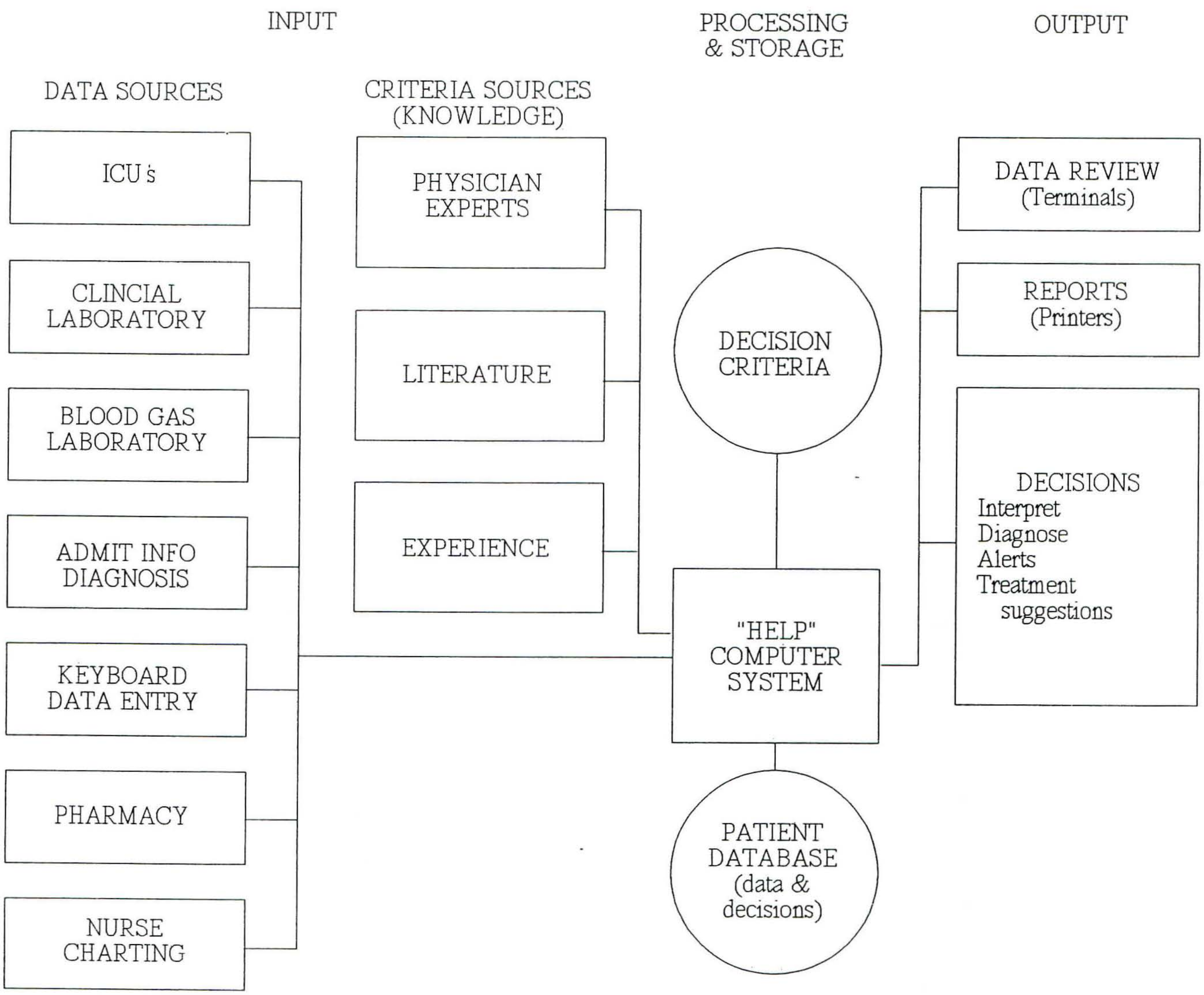

Figure 196–4. Patient data flows into the HELP decision-making computer system from a variety of data sources. The decision-making criteria (knowledge base) are then automatically applied to the data, giving an output of computer-aided decisions. A variety of outputs are generated, including information for review on computer terminals, printed reports, and possible medical decisions.

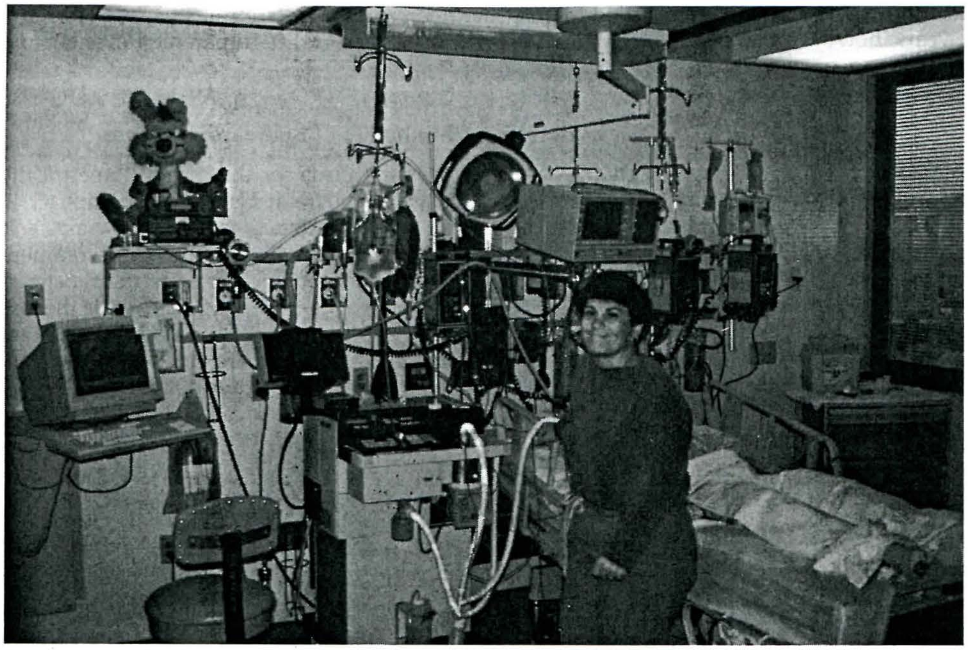

Figure 196–5. A photograph of a patient's room showing a computer terminal at each bedside. Also note the box in the center above the bed; this box is the Medical Information Bus bedside interface. Intravenous pumps, pulse oximeters, and ventilators are connected to the computer system through the Medical Information Bus. (See Color Plate Section of this textbook.)

ties and medical schools and their affiliated hospitals. As a result of the interest and excitement of having computer-assisted care in the ICU, several commercial vendors became interested in the marketing of such systems. A number of commercially available computerized ICU systems that have decision-support capabilities are beginning to become available.

EXAMPLES OF COMPUTERIZED DISPLAYS AND REPORTS

Figure 196–5 shows the scene in our ICU; each ICU room has a patient bed, a bedside terminal, and MIB connections. To satisfy the needs of physicians, nurses, therapists, and others caring for a patient, both bedside terminal screen reviews (displays) and printed reports are generated. To meet the clinical management needs required by critically ill patients and to generate an adequate legal record, most computerized patient data management systems generate printed reports for inclusion in the conventional paper medical record. In the future, a true "electronic" and "paperless" record may replace paper records entirely. However, for the moment, the limitations of display size and the convenience of paper outweigh the technologic advantages of a "paperless" data review.

A few examples of display screen formats and printed

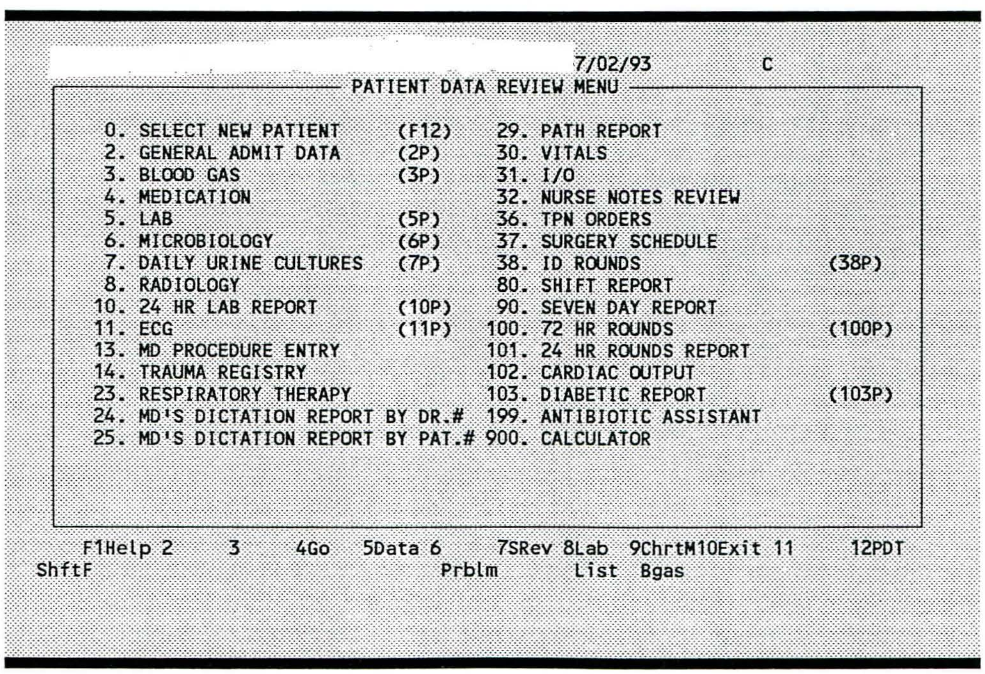

Figure 196–6. Terminal MENU.

```
                                        I 07/02/93          C   ADMT DIAGNOSIS: MULTIPLE INJURIES     REPORT DATE: 07/05/93
DR.                           SEX: M   AGE:  25   HEIGHT: 175   WEIGHT:  95.00   APACHE II:    0   MOF:    0   BSA:  2.10
                                                 ICU 24 HOURS ROUNDS REPORT
CARDIOVASCULAR:  0
  LAST/MAX/MIN    SP:128/161/106   DP: 89/111/ 69   MP:105/135/ 82   HR: 90/150/ 90 | CPK                      CPK-MB
  TIME               CO    CI   HR  SV  SI   VP  MSP  MP SVR LWI PW  PA  PVR   RWI  | LACT     2.7 (03:45)
  JUL 05 06:00     7.00  3.33  106  67  32 16.0M 111 101 13  44  16  44  3.0  12.6

RENAL, FLUIDS, LYTES:  0
  IN   2554 CRYST    2174  COLLOID             BLOOD         NG/PO      380    NA   147 (03:45) K    3.6  (03:45)  CL     112 (03:45)
  OUT  3692 URINE    2225  NGOUT          225  DRAINS    20                    CO2 23.0 (03:45) BUN   17  (03:45)  CRE     .9 (03:45)
  NET -1138 WT      95.00  WT-CHG              LOSS    1222 STOOL              OSM                CRCL         UNA      S.G.  1.020

RESPIRATORY:  0
              pH    PCO2    HCO3    BE    HB    CO/MT   PO2   SO2   O2CT   %O2   AVO2  VO2   C.O. A-a  QS/QT  PK/ PL/PP  MR/SR
  05 05:05 A  7.42  34.4    22.1   -1.1  11.5   2/ 1    81    94   15.3    40                     117          0/  0/ 5  15/ 0
          SAMPLE # 13, TEMP 37.5, BREATHING STATUS : ASSIST/CONTROL

              VENT  MODE  VR   Vt   O2%   PF  IP    MAP   PK   PL  PP  m-Vt  c-Vt  s-Vt  MR  SR  TR  m-VE  s-VE  t-VE  Cth   Pc
  05 12:25  B-II  A/C   15  750   40    50              36   30   5   830   715         15          10.7              28.6
  05 05:34  B-II  A/C   15  750   40    50              38   32   5   920   798         15          12.0              29.6
  -- NO SPONTANEOUS PARAMETERS WITHIN THE LAST 24 HOURS --

 F5-Print   F6-Notes   SF6-X Ray   F7-Vitals   SF7-Resp   F8-Lab   SF8-Urine   F9-Micro   SF9-B Gas   F11-Hemo   F12-New Patient
```

Figure 196–7. Twenty-four–hour ROUNDS (top).

reports are presented to illustrate the convenience and the advantages of computerized data review and reporting. The patient reviewed was a 25-year-old man who sustained an accidental injury and who was admitted to our Shock Trauma Unit.

Most computer systems are "menu"-driven; this means that the clinical user chooses a selection from a menu similar to that shown in Figure 196–6. For example, choosing option 101, the "24 HR ROUNDS REPORT," would yield the display shown in Figure 196–7. This terminal display shows data organized by physiologic system. Note that the blood pressures, cardiac output, and enzyme values related to cardiac function are shown. Data in this rounds report come from a wide variety of locations, including the admitting office, the medical records department, the bedside monitor, the nursing charting input, the chemistry laboratory, the blood gas laboratory, and the respiratory therapy department. The second screen of the record is shown in Figure 196–8 and presents data from the neurologic and psychologic assessment (note the Glasgow Scale Score of 14) as well as other data. Figure 196–9 shows the results of microbiologic analysis and the fact that there was a "positive micro result" along with the medication data. Typically, the 24-hour rounds report is printed; however, display terminal review is most convenient for physicians who access the computer system from their homes or offices.

If a physician wanted to review more detailed hemodynamic data while reviewing the 24-hour rounds report from the terminal, he or she could push the F11 key on the extended keyboard and within a few seconds would see the display shown in Figure 196–10. Note the computerized interpretation of the hemodynamic results as well as the listing of cardioactive medications (dopamine in this case) relevant to the results.

Pressing the F8 key would yield the laboratory results. An example screen is shown in Figure 196–11. Note that high and low values are marked with an H or an L, respectively. On the actual screen, these values are highlighted in

```
                                        I 07/02/93          C   ADMT DIAGNOSIS: MULTIPLE INJURIES     REPORT DATE: 07/05/93
DR.                           SEX: M   AGE:  25   HEIGHT: 175   WEIGHT:  95.00   APACHE II:    0   MOF:    0   BSA:  2.10
                                                 ICU 24 HOURS ROUNDS REPORT
NEURO AND PSYCH:  0
  GLASGOW 14  (07:55)     VERBAL          EYE           MOTOR           PUPILS            ICP

COAGULATION:  0
  PT    12.5    (03:45) INR     1.4  (03:45) PTT      34  (03:45) PLATELETS    52  (03:45) FIBR               D-DIMER

METABOLIC --- NUTRITION:  0        BEE     2073
  KCAL      159  GLU     87   (03:45)  ALB     1.9    (03:45)   CA   7.7    (03:45) TRG
  KCAL/N2   122  UUN                   I-CA                     PO4  1.5    (03:45) MG                  CHOL     78      (03:45)

GI, LIVER, AND PANCREAS:  0
  HCT     32.1 (03:45) TOT BILI  3.4  (03:45) ALT    25    (03:45) ALKPO4    71  (03:45) LDH    587  LIPASE
  GUAIAC               DIR BILI   .5  (03:45) AST   135    (03:45) GGT       13  (03:45) AMYL        GAST Ph  7.0, 7.0, 7.0, 7.0,

INFECTION:  0
  WBC  7.2 (03:45) TEMP  38.1 (08:45)    DIFF  91 B,  4P,  2L,  3M,  E (03:45) GRAM STAIN: SPUTUM             OTHER
  Positive Micro Results, F9 for detail

SKIN AND EXTREMITIES:

 F5-Print   F6-Notes   SF6-X Ray   F7-Vitals   SF7-Resp   F8-Lab   SF8-Urine   F9-Micro   SF9-B Gas   F11-Hemo   F12-New Patient
```

Figure 196–8. Twenty-four–hour ROUNDS (middle).

I 07/02/93 C ADMT DIAGNOSIS: MULTIPLE INJURIES REPORT DATE: 07/05/93
DR. SEX: M AGE: 25 HEIGHT: 175 WEIGHT: 95.00 APACHE II: 0 MOF: 0 BSA: 2.10
ICU 24 HOURS ROUNDS REPORT

INFECTION: 0
WBC 7.2 (03:45) TEMP 38.1 (08:45) DIFF 91 B, 4P, 2L, 3M, E (03:45) GRAM STAIN: SPUTUM OTHER
Positive Micro Results, F9 for detail

SKIN AND EXTREMITIES:

MEDICATIONS:

MORPHINE, INJ	30.00	DOPAMINE, INJ	.00	TAP WATER, LIQUID	60.00
MIDAZOLAM (VERSED), INJ	15.00	RANITIDINE HCL (ZANTAC),	150.00	JEVITY, LIQUID	150.00
METRONIDAZOLE (FLAGYL),	2000.00	POTASSIUM CHLORIDE, INJ	43.46	TAP WATER, LIQUID	150.00
CEFTAZIDIME (FORTAZ), IN	3000.00	POTASSIUM PHOSPHATE, INJ	9.00		
VANCOMYCIN (VANCOCIN), I	2000.00	MAGNESIUM SULFATE 50%, I	1.00		

TUBES:
VEN ________ ART ________ SG ________ NG ________ FOLEY ________ ET ________ TRACH ________ DRAIN________
CHEST ______________ RECTAL _______ JEJUNAL ________ DIALYSIS ________ OTHER ______________________________

--- End of Report ---

F5-Print F6-Notes SF6-X Ray F7-Vitals SF7-Resp F8-Lab SF8-Urine F9-Micro SF9-B Gas F11-Hemo F12-New Patient

Figure 196–9. Twenty-four–hour ROUNDS (bottom).

color to make them clearly visible. All laboratory results are available, but only the chemistry data are shown here.

Figure 196–12 shows a transcribed radiography report for the patient. Typically, after the film is read and observations are dictated, on-screen review is available within 1 hour. Figure 196–13 shows an example of nursing notes for the patient. Figure 196–14 shows a typical respiratory therapy display screen. All of the reports noted can also be printed.

A shift report is generated for each 12-hour period. Figure 196–15 is a shift report for the same patient. Note that vital signs (all automatically acquired with the MIB) are shown graphically, and fluid intake and output results are shown for the most current 12 hours and are summarized for an entire 24-hour period. In this case, the patient has a 5856 net balance gain. Since the patient was not weighed, a comparison of weight gain or loss cannot be made with fluid status. Below the vital sign graphics are measurement data. Some of the data are acquired automatically, and some are entered manually. Laboratory data are transmitted from the laboratory computer system to the ICU-HELP system. At the bottom of the screen, the medications that have been given are shown, with the amounts and times indicated graphically. The infusions are noted next. For example, infusion of dopamine, 4.40 μg · kg^{-1} · min^{-1}, was begun at 2200 hrs. The infusion data comes from intravenous infusion pumps with MIB interfaces. Next, blood gas data with computerized interpretations are presented. Note also that if arterial and venous blood gas values are available for the same time

Text continued on page 1769

I 25Y M 07/02/93
HT 175 CM WT 95.00 KG BSA 2.10 SQM DR CHRISTENSEN, B

TIME	CO	CI	HR	SV	SI	MP	MSP	PA	RA	PW	PVR	SVR	RWI	LWI
NORMAL HI	7.3	3.50	89	101	48	105	123	19	5	12	1.0	18	11.0	85
NORMAL LOW	2.9	2.80	49	47	38	70	80	9	1	4	0.5	12	8.0	48

Review/Print Cardiac Output

JUL 05 06:00	7.0	3.33	104	67	32	98	111	31	10	10	3.0	13	12.6	44
LV PARAMETERS ARE WITHIN NORMAL LIMITS														
JUL 04 04:00	7.4	3.41	111	67	31	86	98	37	12	12	3.4	10	13.0	36
MILD LV DYSFUNCTION														
JUL 03 04:00	7.6	4.00	116	66	34	64	77	33	12	16	2.2	7	12.7	29
JUL 03 03:52 DOPAMINE (INTROPIN) 10.70 MCG/KG/MIN														
MODERATE LV DYSFUNCTION														
JUL 02 22:10	5.1	2.68	114	45	24	66	77	31	14	16	2.9	10	6.7	19
JUL 02 22:00 DOPAMINE (INTROPIN) 4.40 MCG/KG/MIN														
MODERATE LV DYSFUNCTION														

>

F9 - SCROLL

Figure 196–10. Hemodynamics.

C

CHEM 7

DATE	TIME		NA MMOL/L	K MMOL/L	CL MMOL/L	CO2 MMOL/L	BUN MG/DL	GLU MG/DL	CREAT MG/DL
05JUL	03:45	SE	**147H**	3.6	112	23	17	87	.9
04JUL	04:05	SE	146	3.6	**113H**	22	**22H**	71	1.0
03JUL	23:00	SE	144	3.8	**115H**	**19L**	**21H**	80	1.1
03JUL	03:55	SE	145	3.6	112	20	**22H**	101	1.2

CHEM 13

DATE	TIME		URAC MG/DL	TPRT GM/DL	ALB GM/DL	CA MG/DL	PHOS MG/L	CHOL MG/DL	TBIL MG/DL	DBIL MG/DL	ALKP IU/L	GGT U/L	LDH U/L	AST U/L	ALT U/L
05JUL	03:45	SE	4.6	**4.3L**	**1.9L**	**7.7L**	**1.5L**	78	**3.4H**	**.5H**	71	13	**587H**	**135H**	25
04JUL	04:05	SE	4.2	**4.3L**	**2.1L**	**7.6L**	**1.9L**	65	**7.4H**	**1.1H**	53	15	**632H**	**149H**	21
03JUL	03:55	SE	4.4	**4.0L**	**2.1L**	**7.0L**	2.6	71	**4.1H**	**.9H**	35	17	**534H**	**103H**	19
02JUL	09:50	SE	5.6	**3.8L**	**2.1L**	**7.2L**	**4.6H**	49	**3.3H**	.3	22L	15	**796H**	**139H**	26

LACTIC ACID, PLASMA (VENOUS)

DATE	TIME		LA-PLS MMOL/L
05JUL	03:45	PL	**2.7H**
04JUL	04:05	PL	**3.7H**

Figure 196–11. Laboratory data.

I 07/02/93 C

RADIOLOGY REPORT

PORTABLE AP SUPINE CHEST #7: 4 Jul 1993

FINDINGS: Endotracheal tube, nasogastric tube, Swan-Ganz catheter, median sternotomy wires, and mediastinal drain remain in place. Enteral feeding tube has been positioned with the tip in the proximal jejunum. Cardiac silhouette is slightly increased in size. There is persistent widening of the superior mediastinum which likely represents a combination of increase in central venous pressure and post-traumatic/postoperative change status post repair of a right innominate artery laceration. Central interstitial edema may be present. There is volume loss involving the retrocardiac lung bilaterally. Bilateral pleural effusions are present. There is no consolidation or pneumothorax.

MFE/TL491
D: 4 JUL 1993
T: 4 JUL 1993

Figure 196–12. Radiology report.

FLOOR COMMENTS

NAME·
DR. SEX: M
ADMIT DIAGNOSIS: MULTIPLE INJURIES
NO. AGE: 25
ROOM: HEIGHT: 175 cm
WEIGHT: 95.00 kg BSA:2.10 SQM
ADMIT DATE: JUL 02 05:23

DATE/TIME	ACTION	
05 JUL 12:07	EMOTIONAL SUPPORT	: Emotional support - patient, Emotional support - family, Vented feelings, Discussed hospitalization, Discussed treatment, Discussed disease process, Tim spent 5 min. (es)
05 JUL 12:01	GU OUPUT	: Foley cath out 185 ml, Amber, Clear Mean BP 103
	OXIMETRY	: STO2 (finger): 95
05 JUL 11:16	INVASIVE LINES & TUBES	: Cordis, Right, Jugular, Dressing changed, Time spent 5 min. (D), Betadine, None, Clean, Dry
05 JUL 11:13	INVASIVE LINES & TUBES	: Opticath swan, Right, Jugular, Removed
05 JUL 10:59	TUBE/DRAIN MANAGEMENT	: Small ga. feed tube, Comment: FULL STRENGTH JEVITY
05 JUL 10:00	IRRIGATION	: Small ga. feeding tube, Tube feed infuse rate: 30 cc/hr
05 JUL 09:59	GU OUPUT	: Foley cath out 160 ml, Amber, Clear Mean BP 104
	OXIMETRY	: SVO2: 65, STO2 (finger): 92

Press <Enter> for more data, <Esc> to quit, F6 = Search time, F7 = Print, F12 = New patient

Figure 196–13. Nurse comments.

C

RESPIRATORY CARE CHARTING

07/05/93 VENTILATOR MONITORING

	VENT	MODE	VR	Vt	O2	PF	IP	TEMP	IE RATIO	PK	PL	MAP	PP	m-Vt	c-Vt	s-Vt	MR	SR	TR	m-VE	s-VE	t-VE	Cth	aOX	vOX	Pc	CF
05 12:25	B-II	A/C	15	750	40	50		35.0	1: 2.8	36	30		5	830	716		15			10.7			28.6	95			3.7
05 09:57	B-II	A/C	15	750	40	50		35.0	1: 2.8	36	28		5	710	596		15			8.9			25.9	93			3.7
05 07:25	B-II	A/C	15	750	40	50		35.0	1: 2.6	35	32		5	910	799		15			12.0			29.6	95		20	3.7
05 05:34	B-II	A/C	15	750	40	50		35.0	1: 2.8	38	32		5	920	798		15			12.0			29.6	94	66		3.7
05 03:41	B-II	A/C	15	750	40	50		35.0	1: 2.7	40	33		5	880	751		15			11.3			26.8	91	62		3.7
05 01:42	B-II	A/C	15	750	40	50		35.0	1: 2.9	37	30		5	780	620		15			9.3			24.8	95	63		5.0

07/05/93	DUR/ENTRY	OBSERVATIONS
05 12:25	10/12:26	- INTERFACE: ORALTRACH TUBE; ALARMS CHECKED; TEMP SETTING: 35.0; POSITION: SEMI-FOWLER; PATIENT CONDITION: CALM THERAPIST: LARRY RRT
05 09:57	10/09:58	- INTERFACE: ORALTRACH TUBE; ALARMS CHECKED; TEMP SETTING: 35.0; POSITION: SEMI-FOWLER; PATIENT CONDITION: CALM THERAPIST: LARRY RRT
05 07:25	10/07:27	- INTERFACE: ORALTRACH TUBE; ALARMS CHECKED; TEMP SETTING: 35.0; POSITION: SEMI-FOWLER; PATIENT CONDITION: CALM THERAPIST: LARRY RRT
05 05:34	5/05:36	- INTERFACE: ORALTRACH TUBE; ALARMS CHECKED; TEMP SETTING: 35.0; POSITION: SEMI-FOWLER; PATIENT CONDITION: SEMI CONSCIOUS, CALM; THERAPIST: TED RRT

----------- Press <Enter> for more...

Press <Enter> to continue, <Esc> to quit, <Page Up>, <Page Down>, arrow keys, <F5> to change search time, <F6> to print

Figure 196–14. Respiratory therapy data.

```
--------------------------------------------- SHIFT REPORT ---------------------------------------------
|                                07/02/93.18:01 to 07/03/93.06:00                                       |
|                                                                                                       |
| Patient:                                       #            Room:           Age: 25     Sex: M        |
| Adm Wt:   75.00 KG  Ht: 175 CM  BSA: 1.90 SQM   Dr: CHRISTENSEN, BRENT J      S#: 07/02-07/03.06:00   |
|                                                                                                       |
---------------------------------------------------------------------------------------------------------

                  Temp = Oral, Rectal, Axillary, Core, Foley, Ear, sKin    *                                       *
                  BP = Systolic/Diastolic,     HR = *                      ***************** INTAKE/OUTPUT ******************
                  $ = Systolic AND HR,     & = Diastolic AND HR            *                                       *
                    07/02/93.18:01 to 07/03/93.06:00                                     LAST 12 HRS     24 HR. TOTAL
                  18  19  20  21  22  23   0   1   2   3   4   5   6
         --------|+---+---+---+---+---+---+---+---+---+---+---+---+                     18-06            06-06
          235 41 |                                                                       -----            -----
                 |                                                          INTAKE
          220 40 |                                                            Colloid      1310             2435
                 |                                                            Non-Blood IV  807             8444
          205 39 |                                                              TOTAL INTAKE 2117          10879
                 |
          190 38 |                                                          OUTPUT
                 |------------------------------------CCCC-CCCCCCCC           Foley cath out 2460           3610
          175 37 |                       C   CCCCCCCCCC                       #1 Waterseal dr. 30             30
                 |*                  CCCCC CCC                                Colostomy drg.   50             50
          160 36 |                  C                                         NG tube drg.    300            300
                 |                                                            Phlebotomy output 40            40
          145 35 |                                                            Insensible loss 480            993
                 |    *                                                         TOTAL OUTPUT  3360           5023
          130 34 | *** ****          $
                 |---------***-------------------------------------
          115    |  S S       $*  * *    S        ******************           NET BALANCE   -1243           5856
                 |S          S      **$**    **$
          100    | S S SSS  S       SS S $$$$$SS     S
                 |             SS                 SSSS SSSSSSSSSSSSS        MAXIMUM TEMPERATURE = 37.7
           85    |        SS       S
                 |----D-------D----DS---------------------------            WEIGHTS(KG):
           70    |     DDD  DD           D                                    Today's (Est./state):      75.00
                 |D DD     D    D  D   D  D                                      07/02/93.09:15
           55    | D        D    D     D D  DDDDDDDDDDDDDDDDDDDDDDDDDD         Previous:                   N/A
                 |                    D                                       Weight Change:              N/A
           40    |
                 |             *                                            *                              *
           25    |                                                          *********** LAB RESULTS ***********
                 |                                                          *                              *
           10    |                                                            WBC     1.6    JUL 03 93 03:55
                 18  19  20  21  22  23   0   1   2   3   4   5   6           HCT    28.1    JUL 03 93 03:55
         --------|+---+---+---+---+---+---+---+---+---+---+---+---+           HGB     9.9    JUL 03 93 03:55
                                                                              PLATE  96      JUL 03 93 03:55
Respiratory Rate                   18 18  18      19      18      20
GLASCOW COMA SCORE                 3                                          NA    145      JUL 03 93 03:55
Right Atrial Pressu                14 12  10      14      12      12          K       3.6    JUL 03 93 03:55
PA systolic                        40 36  38      44      46      44          CL    112      JUL 03 93 03:55
PA diastolic                       26 18  18      24      26      24          CO2    20      JUL 03 93 03:55
PA mean                            31 24  24      30      33      30          BUN    22      JUL 03 93 03:55
Pulmonary Artery We                16 14  12      16      16      16          GLUC  101      JUL 03 93 03:55
Mean BP                            68 70  69      65              68          CREAT   1.2    JUL 03 93 03:55
SVO2:                              65 73  77      69              66
STO2 (finger):                    100 97  95      93              93
Foley cath out                    750   400      480     450     380
Net Urine Output                                                2460
NG tube pH                          7.0           7.0
#1 Waterseal dr.                                                  30
        ---------|+---+---+---+---+---+---+---+---+---+---+---+---+
                 18  19  20  21  22  23   0   1   2   3   4   5   6

                                                          07/02/93 18:01 to 07/03/93 06:00
                      DRUG NAME                DOSE    18  19  20  21  22  23   0   1   2   3   4   5   6   DRUG NAME
                                            ----------|+---+---+---+---+---+---+---+---+---+---+---+---+

                    ** Scheduled Drugs **
IMIPENEM CILASTATIN, IVPB                  500 MGM                          1                        1    IMIPENEM CILASTAT

                     ** PRN Drugs **
# MIDAZOLAM, IV                           2.50 MGM    .                  1     1                 1    1 # MIDAZOLAM
                                            ----------|+---+---+---+---+---+---+---+---+---+---+---+---+
                                                       18  19  20  21  22  23   0   1   2   3   4   5   6
-------------------------------------------------------------------------------------------------------------------
A                      #        Rm:        PERMANENT REPORT   Print Time: 07/05/93.16:58    S#: 07/02-07/03.06:00
                                                  - 1 -
```

Figure 196–15. *A and B,* Shift report for a 12-hour ICU nursing shift.

Illustration continued on following page

```
                                                                       18  19  20  21  22  23   0   1   2   3   4   5   6
                                                             ----------|+---+---+---+---+---+---+---+---+---+---+---+---+
# MORPHINE, IV                                         5.00 MGM                                1   2                     11 # MORPHINE

                            ** Infusions **
DOPAMINE 400 MGM, IVD                                          |                               1111111111111111111111111111 DOPAMINE
    <D5W 100 ML, INJ>                                          |                           44788880000000000000000000000000
                                           RATE     .100 MCG/KG/M|                           44199997777777777777777777777777
---------------------------------------------------------------|----------------------------------------------------
LACTATED RINGERS 100 ML, IVD                                   |                           22111                            LACTATED RINGERS
                                                               |                           22000
                                           RATE        1 ML/HOUR|                           55000
---------------------------------------------------------------|----------------------------------------------------
NACL 0.45% 607 ML, IVD                                         |                                                            NACL 0.45%
                                           RATE      100 ML/HOUR|                                111111111111111111111111111
---------------------------------------------------------------|----------------------------------------------------
FRESH FROZEN PLASMA 230 ML, IVD                                |                                    **                      FRESH FROZEN PLAS
    <O  POSITIVE, 0.>                                          |
    <NO.    2089887>                                           |
FRESH FROZEN PLASMA 230 ML, IVD                                |                                     **                     FRESH FROZEN PLAS
    <O  POSITIVE, 1>                                           |
    <NO.    1359868>                                           |
FRESH FROZEN PLASMA 230 ML, IVD                                |                                      *                     FRESH FROZEN PLAS
    <O  POSITIVE, 1>                                           |
    <NO.    1359834>                                           |
FRESH FROZEN PLASMA 180 ML, IVD                                |                                      **                    FRESH FROZEN PLAS
    <O  POSITIVE, 1>                                           |
    <NO.    133637>                                            |
FRESH FROZEN PLASMA 230 ML, IVD                                |                                       **                   FRESH FROZEN PLAS
    <O  POSITIVE, 1>                                           |
    <NO.    1359888>                                           |
FRESH FROZEN PLASMA 210 ML, IVD                                |                                        *                   FRESH FROZEN PLAS
    <O  POSITIVE, 1>                                           |
    <NO.    1836597>                                           |
                                                     ----------|+---+---+---+---+---+---+---+---+---+---+---+---+
                                                               18  19  20  21  22  23   0   1   2   3   4   5   6

JUL 03 93     pH    PCO2     HCO3     BE    HB   CO/MT    PO2    SO2   O2CT   %O2  AVO2  VO2   C.O.  A-a  Qs/Qt  PK/ PL/PP  MR/SR
              --    ----                                  ---
NORMAL HI    7.45   39.3     25.1    2.5  17.7   2/ 1                               5.5  300   7.30   18     5
NORMAL LOW   7.35   25.9     15.0   -2.5  13.7   0/ 1     69     92   18.7          3.0  200   2.90           0

03 04:01 V   7.40   34.7     21.2   -2.4   9.8   2/ 1     32     67    9.3    40                                    /   / 5  18/
03 04:00 A   7.42   30.0     19.3   -3.6  10.0   2/ 1     87     96   13.5    40   4.05 308   7.60  116    13       /   / 5  18/
             SAMPLE # 11, TEMP 37.0, BREATHING STATUS : ASSIST/CONTROL
             NORMAL ARTERIAL ACID-BASE CHEMISTRY
             SEVERELY REDUCED O2 CONTENT (13.5) DUE TO ANEMIA (LOW HB)
             PULSE OXIMETER SO2  92.0
03 00:06 A   7.36   32.5     18.1   -5.9  12.0   2/ 1    128     97   16.5    80                     312            34/ 29/ 5  18/
02 22:02 V   7.23   48.6     19.8   -7.5  11.3   2/ 1     33     63   10.0   100                                    /   / 5  18/
02 22:01 A   7.28   40.2     18.5   -7.5  11.2   2/ 1     82     94   14.9   100   4.98 254   5.10  471    29       /   / 5  18/
02 18:51 V   7.12   61.6     19.3  -10.1   9.4   2/ 1     46     71    9.4    93

------------------------------------------------------- HEMODYMANICS -------------------------------------------------------

NORMAL HI        7.30  3.50  89 101  48 105  123 19  5.0  12  1.0  18  11.0  85
NORMAL LOW       2.90  2.80  49  47  38  70   80  9  1.0   4  0.5  12   8.0  48

TIME               CO    CI  HR  SV  SI  MP  MSP PA   RA  PW  PVR SVR   RWI LWI

JUL 03 04:00      7.6  4.00 116  66  34  64   77 33   12  16  2.2   7  12.7  29
         JUL 03 03:52  DOPAMINE (INTROPIN) 10.70 MCG/KG/MIN
         MODERATE LV DYSFUNCTION

JUL 02 22:10      5.1  2.68 114  45  24  66   77 31   14  16  2.9  10   6.7  19
         JUL 02 22:00  DOPAMINE (INTROPIN)  4.40 MCG/KG/MIN
         MODERATE LV DYSFUNCTION

                                                               18  19  20  21  22  23   0   1   2   3   4   5   6
                                                     ----------|+---+---+---+---+---+---+---+---+---+---+---+---+
  07/02/93.22:00  To 07/03/93.06:00          CODY, RN                              *********************************

----------------------------------------------------------------------------------------------------------------------------
B                          #            Rm:         PERMANENT REPORT   Print Time: 07/05/93.16:58   S#: 07/02-07/03.06:00
                                                          - 2 -
```

Figure 196–15 *Continued*

intervals that hemodynamic data are available, then arterial-to-venous oxygen content differences and oxygen consumption are calculated. Finally, the nurse or nurses who cared for the patient are shown, with the interval of care provision indicated by a row of asterisks.

THE FUTURE

The future of computers in the ICU is bright. With the improvement in performance of microprocessors and the continuous reduction in their cost, these devices will continue to become integral components of the ICU. The availability of adequate computer hardware will not be the limiting factor.

The use of computers to improve the speed and accuracy of communication of patient data is already well established. The use of computers to guide patient therapy is a new and exciting concept that, based on early experience, appears to be well accepted by medical professionals and that seems to provide improved outcomes. The limiting factors in the future use of computers in the ICU will be (1) human, cultural, and sociologic issues; (2) development of standards for sharing data and medical knowledge; (3) establishment of data acquisition methodologies that meet the competing demands of "What is enough data?" and "What can we afford?"; and finally, (4) societal views about the rationing of patient care.

SUMMARY: A MATCH MEANT TO BE!

Combining the computer and the modern ICU is certainly a match meant to be. Several advantages of computer systems in the ICU have been demonstrated. These systems can assist in data collection, provide computational capability, assist in data communications and integration of data, improve record keeping, enhance report generation, assist in medical decision making, and assist with protocol-directed care. As Dr. John J. Osborn, a pioneer in the field of computerized ICU, said so well 15 years ago,[56]

"The great mass of useful numbers we generate by computer has got to be tamed and controlled. We have learned how to make the measurements. Now we must learn how to handle the resulting data and present them in understandable terms. Used right, automation can integrate these data, simplify them, scan them and evaluate them. Automation is not a cold-blooded monster-machine between us and the patient. It is a tool to expand our medical power, to let us get closer to the patient, and take better care of him."

We who are now using the computer to assist with patient care and those who will be in the future should take confidence in Dr. Osborn's comments and make his dream our reality.

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CHAPTER 197

Computerization: Solutions to Problems in the Input, Manipulation, and Storage of Intensive Care Unit Data

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Nearly 15 years have passed since I first wrote on this topic for the first edition of this textbook. Over those 15 years, much progress has occurred in the intensive care unit and in the world of computers. The forces that drive computerization of the clinical world have increased.[1–2] They include demands for increased control of resources, decreased operational costs, and excellent quality care. The federal government, which is the United States' largest purchaser of healthcare, is expected to restructure the healthcare reimbursement system. In a similar fashion, employers are initiating major strategy changes to reduce their healthcare costs and are demanding that healthcare expenditures be carefully managed. The Institute of Medicine, an organization chartered by the National Academy of Sciences to advise the federal government on health policy, identified "the prompt development and implementation of computer-based patient records (CPRs)" as a key factor in the response to the present and future challenge of healthcare. The Institute of Medicine is referring to a totally computerized record-keeping environment in which clinicians perform all documentation duties at electronic workstations. The Institute of Medicine report, entitled "The Computer-Based Patient Record," specifies the following:

As its first step, the [Institute of Medicine] study committee examined why previous work had not resulted in widespread improvement of patient records and asked whether and how another effort might be successful. The committee identified five conditions in the current health care environment that increase the likelihood of success.

1. The uses of and legitimate demands for patient data are growing. Part of this growth can be attributed to increased concern about the content and value of clinical therapies and a recent intense focus on health services research.
2. More powerful, affordable technologies to support computer-based patient records are now available.
3. Increasingly, computers are being accepted as a tool for enhancing efficiency in virtually all facets of everyday life.
4. Demographic factors such as aging population (which results in a growth in chronic diseases) and the continued mobility of Americans create greater pressures for patient records that can manage large amounts of information and are easily transferable among health care providers.
5. Pressures for reform in health care are growing, and automation of patient records is crucial to achievement of such reform.

The combination of these factors led the committee to conclude that computerization can help to improve patient records and that improved patient records and information management of health care data are essential elements of the infrastructure of the nation's health care system."[3]

However, it is rare to find examples of CPRs in use in hospitals today. Component applications in which clinicians enter or review parts of the traditional paper and radiographic film record at computer workstations do exist.[4] The